Variability in space and time of extreme rainfalls, floods and droughts
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TREND ANALYSIS OF SHORT RAINFALL ANNUAL MAXIMA IN CALABRIA

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ABSTRACT
This paper shows an investigation on temporal and spatial variability of annual maxima of short duration rainfalls (1, 3, 6, 12 and 24 hours) ranging from 1916 to 2000, selected from the rainfall data set of Calabria (southern Italy). To detect changes in the extreme rainfall series the Mann-Kendall non-parametric test has been used at local scale, considering all the stations involved in the region. Moreover the variability of both parameters and quantiles of empirical intensity-duration-frequency relationships for short duration rainfalls has been explored for different time periods. Finally the monthly distribution of the occurrence process of annual maxima of short duration rainfalls has been statistically analysed.

1. INTRODUCTION

A number of bodies and agencies of the United Nations are addressing the problems of climate, its variations and changes. In particular, the World Meteorological Organization and the United Nations Environment Programme have launched certain initiatives, such as the Intergovernmental Panel on Climate Change (IPCC), which is attended by scientists from more than 100 countries and has issued a number of authoritative scientific assessments. The IPCC Fourth Assessment Report (FAR) describes progress in understanding of human and natural drivers of climate variation, pointing out possible scenarios of future climate changes (*IPCC*, 2007).

Although changes in average climate have been monitored and well studied, until recently only a few studies have been focused on extreme weather and climate events. Focusing attention to precipitation, besides detected trends in mean values of rainfall amount for longer aggregation period, the major issues that have concerned researches on the variability of short duration rainfalls relate to data availability, access and quality. In fact to monitor and understand rainfall extremes, daily, hourly and sometimes sub-hourly data over long periods are required. Among the results, the frequency of heavy rainfall events (tropical precipitations and hurricanes) has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour. An opposite trend has been observed in the Sahel region, the Mediterranean basin, southern Africa and parts of southern Asia. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics, also strengthened by higher temperatures.

In Italian country, a statistical non-parametrical analysis on annual maximum hourly rainfall series in Tuscany has shown a significant change since the early 1970s towards increasing extreme events at any duration (*Crisci et al*, 2002). *Bonaccorso et al.* (2005)

applied bootstrap techniques using non-parametrical tests for trend detection of selected annual maximum rainfall series of hourly durations in Sicily, confirming an increasing trend for shorter duration rainfall amounts.

Spatial and temporal variations of the most common hydrological variables in Calabria (air temperature and precipitation), have been characterized by several statistical analyses. Some authors (*Simeone*, 2001; *Cotecchia et al.*, 2004; *Ferrari and Terranova*, 2004; *Coscarelli et al.*, 2004 a,b; *Capra et al.,* 2004) have found a negative trend for annual and monthly precipitations. *Buttafuoco et al.* (2006) have evaluated the temporal persistence of the mean annual precipitations evaluating standardized mean difference of the ten-year mean. A high frequency of drought has been also observed in southern Italy, where desertification risk is dramatically increasing (*Capra et al.*, 1992, 1994; *Mendicino and Versace*, 2002).

In this work the stationarity hypothesis of the annual maximum series of short duration rainfalls in Calabria (Southern Italy) is investigated by means of Mann-Kendall non-parametric test, used both for single series and at regional spatial scale. The differences of estimated values of both parameters and quantiles of empirical intensity-duration-frequency (IDF) curves of short duration rainfalls for different time periods have been explored. Finally the monthly distribution of the occurrence process of annual maxima of short duration rainfalls is statistically analysed in order to detect variability in calendar position during the year at different time periods.

2. PROCEDURES ADOPTED FOR TREND ANALYSIS

2.1 Analysis of time series trends at local scale

The Mann-Kendall (MK) test is a distribution-free, rank-based method for evaluating the presence of monotonic trends in time series, without specifying whether the trend is linear or non-linear. This test has proved to be an effective tool for identifying trends in hydrologic and other related variables, resistant to the effect of extreme values (*Hirsch and Slack*, 1984; *Burn*, 1994). The data are ranked according to time and then each data point is compared to all the data points that follow in time. The MK statistic (*Kendall*, 1962) is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}\left(x_j - x_i\right) \tag{1}$$

where x_i is the data value at time i, n is the length of the data set and sgn(z) is equal to +1, 0, -1 if z is greater than, equal to, or less than zero respectively. The null hypothesis is that the data are independently identically distributed random variables, that is, there is no existing trend in the data set. For the MK statistic holds:

$$E(S) = 0 \qquad \mathrm{Var}(S) = \left[n(n-1)(2n+5) - \sum_{i=1}^{n} t_i\, i(i-1)(2i+5) \right] \Big/ 18 \tag{2}$$

where t_i denotes the number of tied values of extent i. For n larger than 10, the test statistic:

$$Z_{MK} = \frac{S-1}{\sqrt{\mathrm{Var}(S)}} \text{ for } S > 0 \qquad Z_{MK} = 0 \text{ for } S = 0 \qquad Z_{MK} = \frac{S+1}{\sqrt{\mathrm{Var}(S)}} \text{ for } S < 0 \tag{3}$$

follows a standard normal distribution (Kendall, 1962). Local (at-site) significance levels for each trend test can be estimated from the fact that:

$$p = 2[1 - \Phi(|Z_{MK}|)] \quad (4)$$

where Φ( ) is the cumulative distribution function (cdf) of a standard normal variate.

2.2 Analysis of the intensity-duration-frequency relationships

Besides the direct detection of trends in time series of hourly rainfall annual maxima, the search for possible trends in extreme rainfalls has been focused on the time variability of the intensity-duration-frequency (IDF) relationships for short duration rainfalls, which relate rainfall heights $h_{t,T}$ and durations t for assigned return periods T. The most common formula used in Italy for interpolating IDF curves is the empirical power function:

$$h_{t,T} = a_T\, t^{n_T} \quad (5)$$

where a_T and n_T are parameters assuming peculiar values for each rain gauge and exceedence probability, though actually only the first one depends on return period. The identification of IDF curves has been performed with a statistical analysis of annual maxima of hourly rainfalls with duration 1, 3, 6, 12 and 24 hours. The probabilistic law adopted for the fit to each hourly data series is the Gumbel distribution, with estimation of parameters through equations provided by the method of moments.

3. APPLICATION TO CALABRIA RAIN GAUGES

3.1 Study area and dataset features

The hydrological data analyzed in this work are the annual maxima of hourly duration rainfalls collected in Calabria, a region of southern Italy with an area of 15080 km^2 and a perimeter of about 818 km, out of which 738 km are coastlines. Calabria has an oblong shape with a maximum length of 248 km and a width variable from 111 km to 31 km (fig.1). Although Calabria lacks of high peaks, it is one of the most mountainous regions in Italy, since 42% of the land is mountainous, 49% hilly and only the 9% is flat. The maximum and average altitudes are 2267 m and 597 m above sea level respectively. For its geographic position and morphology, Calabria is a region with high climatic contrasts. In the coastal zones a typical Mediterranean weather is normally observed, characterized by mild winters and hot summers with few precipitations. Particularly on the Ionian side short and heavy precipitations occur, due to the hot southern winds coming from Africa, while on Tyrrhenian coasts western air currents cause more frequent orographic precipitations. Compared to the costal zones, climatic features of the inland zones mainly exhibit colder winters with snow and fresher summer with some precipitations.

Hourly rainfalls have been observed from 1916 by the former Italian Hydrographic Service (now Centro Funzionale of the Calabria Region), and published in national reports from which they were gathered for the present study. The dataset updated at 2000 is formed by 122 hourly rainfall series with at least 10 year of observations (tab.1). The data base contains the marks of the heaviest storms that during the 20th century caused hundreds of victims and intense damages in Calabria region. Among the most damaging rainy events, whose intensities and damages are documented mainly in detailed reports and technical notes edited by the Centro Funzionale, the storms occurred in December 1933, November 1935, March 1943, November 1945, January 1946, October 1951, October 1953, November 1959, January 1973, October 1996, September 2000, July 2006. Within each heavy storm, very high values of rainfall intensity can be detected for hourly time periods, some of which are shown in tab.2.

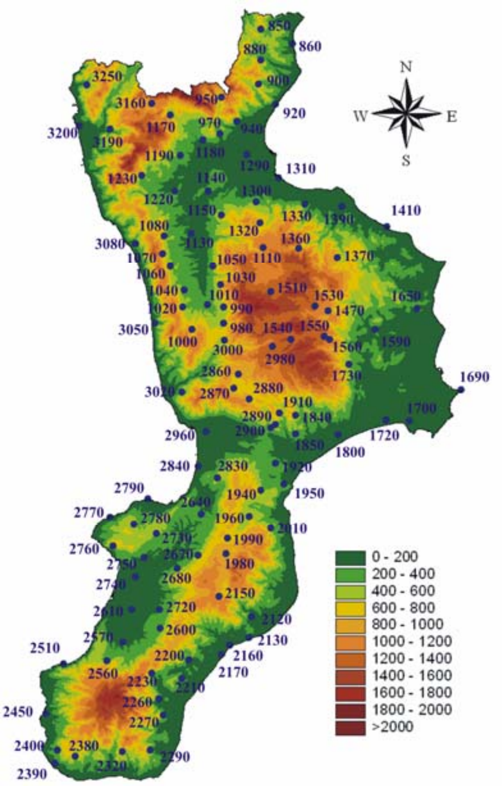

Figure 1. Location of Calabria's rain gauges adopted for analysis.

Dimension of data series ≥	N° of rain gauges
10 years	122
20 years	79
30 years	59
40 years	42
50 years	14

Table 1. Dimensions of annual maxima series of hourly rainfalls of Calabria (period 1916-2000).

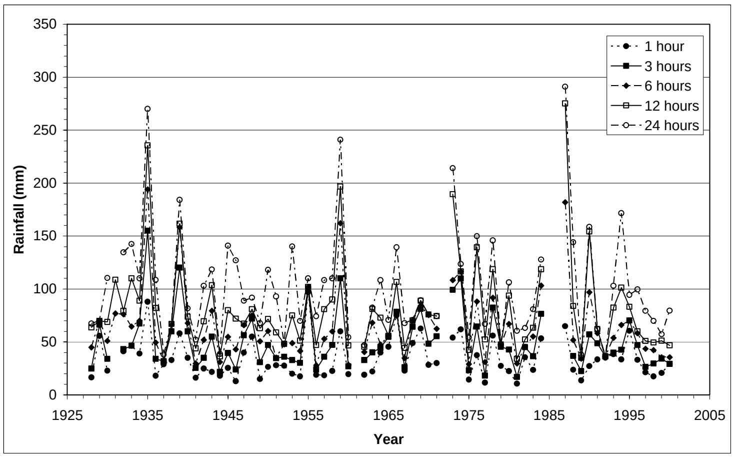

Figure 2. Annual maxima series of 1, 3, 6, 12 and 24-hour rainfalls for rain gauge 1850 (Catanzaro).

In order to perform reliable frequency analysis, data series with too low number of observation years for statistical purposes were discarded. As threshold for our study a value of 30 years of observation has been chosen, thus considering a final set of 59 annual maxima series of rainfalls with duration of 1, 3, 6, 12 and 24 hours, recorded in rain gauges distributed across the region as shown in fig.1. An example of annual maxima series of hourly rainfalls for all the considered durations (rain gauge 1850, Catanzaro) is presented in fig.2.

Though all the data collected for this study can be referred of as hydrological extremes, the presence of outstanding values within the whole data base can be pointed out by means of an exploratory data analysis of the rainfall values for different thresholds and time periods. Some results are shown in tab.3 in terms of percentage of values greater than prefixed thresholds expressed as $\mu+k\sigma$ (with k=1,2,3), where as estimates of μ and σ the sample mean and the standard error of each data series have been assumed. In tab.3 the regional mean of the percentages have been calculated for each time series and rainfall duration with reference to the periods 1921-1960 and 1961-2000. The simple statistical comparison between the two periods shows lower frequency of outstanding hourly rainfall values in time series recorded for the more recent time period.

The some comparisons of percentages of annual maxima of short duration rainfalls greater than quantitative thresholds, subjectively chosen as a distinct prefixed value for each of the durations, are shown in tab.4.

Rain gauge *(code)*	**Rainfall intensity (mm)**
Chiaravalle Centrale *(1960)*	*1935*: 181.6 (3 hours)
Serra S. Bruno *(198)*	*1935*: 90.0 (1 hour), 240.0 (3 hours), 575.0 (24 hours)
Chiaravalle Centrale (*1960)*	*1935*: 181 mm in 3 hours / *1951*: 1495 mm in 72 hours
S. Cristina d'Aspromonte *(1960)*	*1951*: 637.8 (24 hours)
S. Sostene *(2700)*	*1951*: 545.0 (24 hours)
Giffone *(1960)*	*1959*: 160.0 (1 hour), 360.0 (3 hours), 444.0 (6 hours)
Santuario di Polsi *(2250)*	*1972*: 553.0 (32 hours)

Table 2. Examples of high rainfall intensities observed during heavy storms in Calabria.

Threshold value	**1h rainfall** (%)		**3h rainfall** (%)		**6h rainfall** (%)		**12h rainfall** (%)		**24h rainfall** (%)	
	1921-1960	1961-2000	1921-1960	1961-2000	1921-1960	1961-2000	1921-1960	1961-2000	1921-1960	1961-2000
$\mu + \sigma$	18.7	10.5	15.9	10.8	15.2	9.9	16.6	9.8	18.8	9.3
$\mu + 2\,\sigma$	6.5	3.4	7.0	3.4	7.7	3.5	7.1	2.9	6.8	3.1
$\mu + 3\,\sigma$	2.8	1.5	3.7	1.1	3.6	1.0	2.9	1.3	2.4	1.2

Table 3. Mean percentages of annual maxima of short duration rainfalls greater than thresholds expressed as $\mu + K\,\sigma$ for two different time periods.

1h rainfall > 50 mm		**3h rainfall > 100 mm**		**6h rainfall > 150 mm**		**12h rainfall > 200 mm**		**24h rainfall > 300 mm**	
1921-1960	1961-2000	1921-1960	1961-2000	1921-1960	1961-2000	1921-1960	1961-2000	1921-1960	1961-2000
6.2	5.9	2.9	2.0	2.1	1.3	3.0	1.6	1.9	0.4

Table 4. Mean percentage of annual maxima of short duration rainfalls greater than subjectively prefixed thresholds for two different time periods.

3.2 Trend analysis of annual maxima of short duration rainfalls

Though trend analysis of annual rainfall maxima is not frequently carried out directly on the time series, firstly the MK non-parametric test for trend detection has been applied to the 59 time series of annual rainfall maxima. Results show a significant negative trend for about 20% of the time series and no positive trend at all (tab.5).

Duration of hourly rainfalls	**1 h**	**3 h**	**6 h**	**12 h**	**24 h**
negative trend	10	11	12	11	15
No trend	49	48	47	48	44
% trend	*16.9*	*18.6*	*20.3*	*18.6*	*25.4*

Table 5. At-site application of MK test for 59 annual maxima series of short duration rainfalls.

3.3 Evidence of trend analysis on IDF relationships

The search for possible trends of the two parameters a_T and n_T of the empirical intensity-duration-frequency (IDF) relationships for short duration rainfalls (eq.5) has been performed for two different time intervals: 1921-1960 and 1921-2000. For each interval, return period and rain gauge the parameters has been estimated through linear regression of the quantiles of annual maxima series of short duration rainfalls. The criteria used to choose time series for assessing time variability of the parameters of IDF curves are: at least 30 years of data in the period 1921-2000 and at least 5 years of data in the decade 1990-2000, for a total number of 34 series. In fig.3 quantile-quantile plots between parameters a_T and n_T are shown for time intervals 1921-1960 and 1921-2000 with reference to a return period of 100 years. The results clearly point out lower estimated values of a_T parameter for the whole period of observation, 1921-2000, respect to the shortest one, 1921-1960, and a minor influence of n_T parameter on the time period.

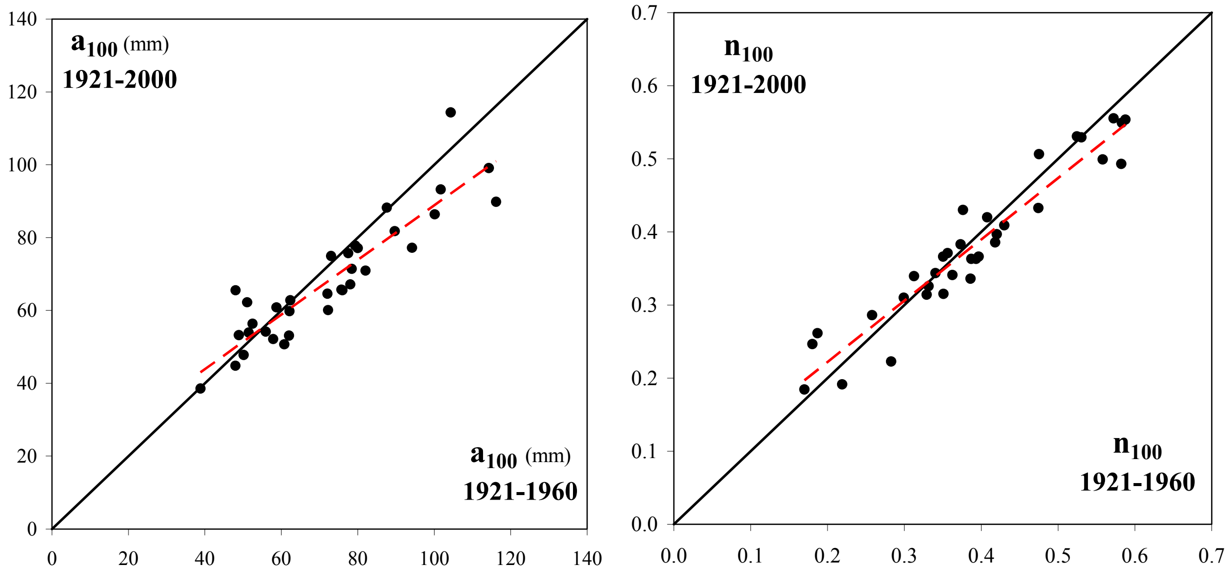

Figure 3. Estimation of parameters of IDF curves for different time periods and T=100 years *(red dashed lined show linear regressions).*

An example of the variability of high quantile estimates obtained from IDF curves for a rain gauge showing significant negative trend (rain gauge 1010, Cosenza) is presented in fig.4.

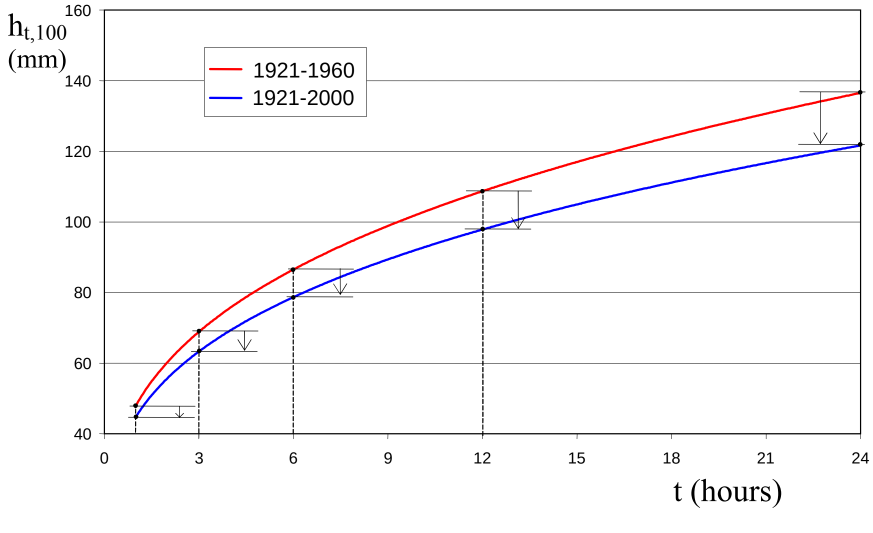

Figure 4. Estimations of quantile $h_{t,100}$ for different time periods (rain gauge 1010, Cosenza).

In the case of the rain gauge 1010 shown in fig.4, the IDF relationships related to 100 years as return period provide lower values of hourly rainfalls for the largest temporal period of observation (1921-2000) up to about 12% of the values estimated for 1921-1960 period.

With reference to the whole set of rain gauges considered in this analysis, the spatial distribution of the ratio between the difference of the quantiles $h_{t,100}$ estimated for the two period 1921-1960 and 1921-2000 for annual maximum rainfalls of duration 1, 3 and 6 hours and the corresponding value $h_{t,100}$ estimated for the first period (1921-1960) are respectively shown as contour plots in fig.5a,b,c,:

$$\frac{h_{t,100\,(1921-1960)} - h_{t,100\,(1921-2000)}}{h_{t,100\,(1921-1960)}} \tag{6}$$

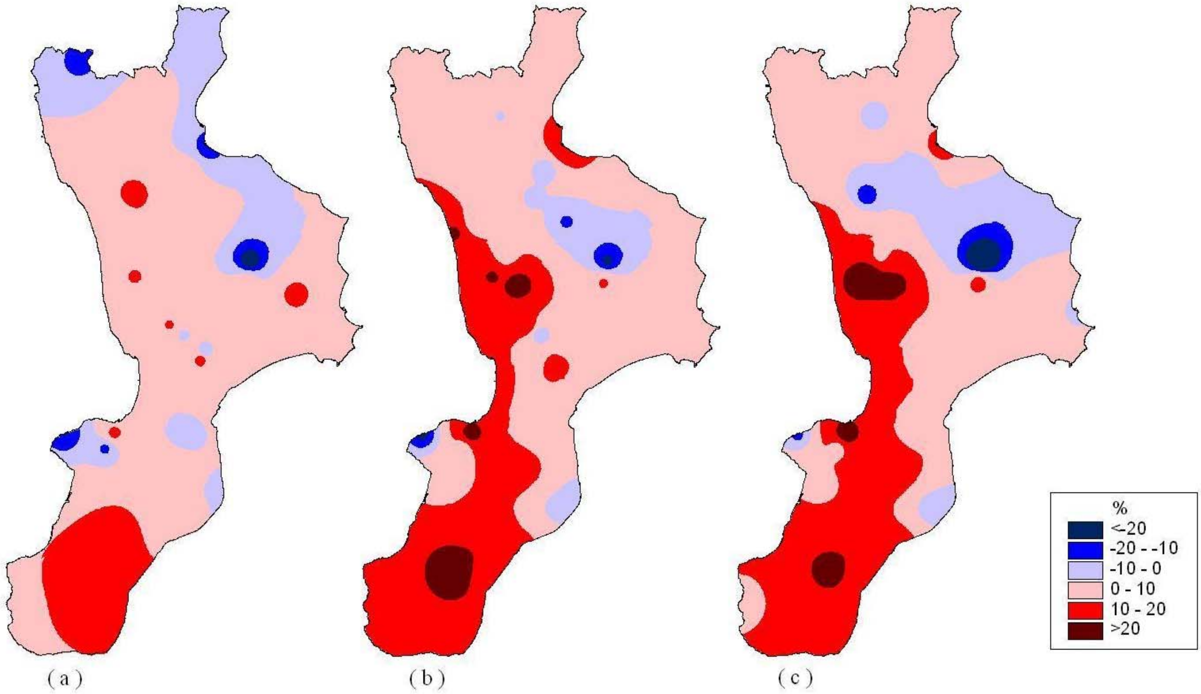

Figure 5. Distribution of the ratio between the difference ($h_{t,100}$ *(period 1921-1960)* - $h_{t,100}$ *(period 1921-2000)*) of annual maximum rainfalls of duration 1 hour *(case a)*, 3 hours *(case b)* and 6 hours *(case c)* and the corresponding value $h_{t,100}$ estimated for the first period (1921-1960).

The plots clearly show positive values of the ratio up to over 20% on large areas of the region, thus pointing out a clear and marked decreasing trend in high quantiles of annual maxima of hourly rainfalls.

3.4 Monthly distribution of dates of annual maxima of short duration rainfalls

A statistical analysis of the occurrence distribution of all the annual maximum values of short duration rainfalls (1, 3, 6, 12 and 24 hours) for the whole set of rain gauges has been performed, in order to point out possible temporal variation of the number of monthly occurrences during different decades. Results show that in the period 1921-1960 the maximum events were mainly located in November and at minor frequency in October (fig.6a), while occurrence analysis in the period 1961-2000 shows an increased variability within months, with the most part of events located in October and a larger spread from September to January (fig.6b). In other terms, extreme rainfall events in the last decades of 20th century show a tendency to anticipate in early autumn, though with greater variability of dates spreading from late summer to early winter.

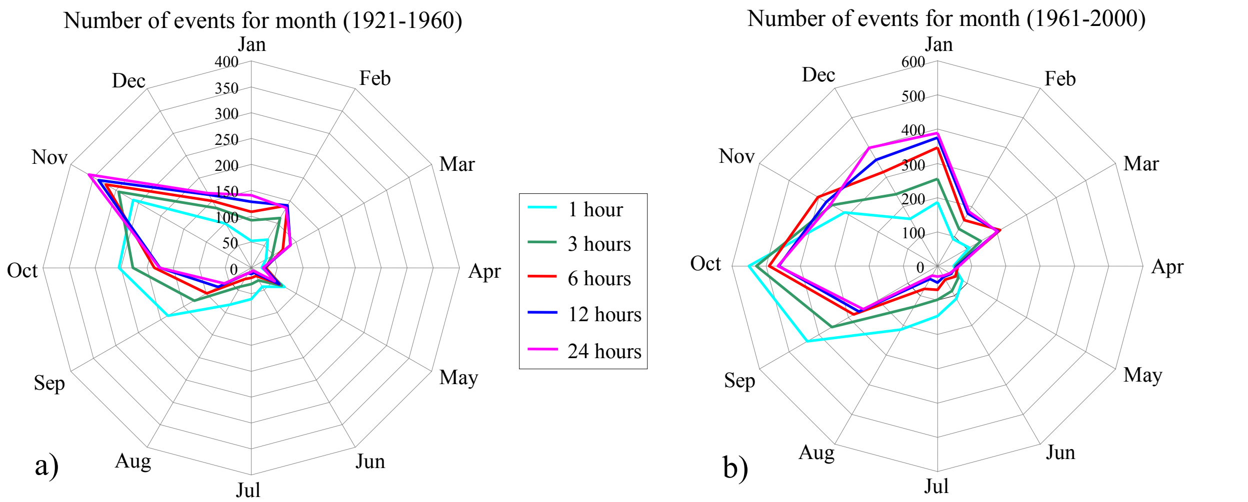

Figure 6. Monthly distribution of occurrences of annual maxima of short duration rainfalls for the two periods 1921-1960 (a) and 1961-2000 (b).

4. CONCLUSION

Detection of changes in extreme rainfalls through the MK non-parametric test has been performed for Calabria region, considering a set of 59 rain gauges with more than 30 years of observation. The main result obtained from the direct trend analysis of the hourly rainfall values is a significant negative trend for about 20% of the time series. The statistical analysis of empirical IDF relationships, evaluated through Gumbel distribution for annual maxima of short duration rainfalls, shows decreasing values of parameters, thus providing lower hourly rainfall values for design purposes in more recent time periods. Finally the monthly distribution of the occurrence dates of annual maxima of hourly duration rainfalls has shown a temporal tendency to anticipate in early autumn, though with greater variability of dates spreading from late summer to early winter. The rainfall variability pointed out in this analysis could change standard practices at our latitude for design of hydraulic works, such as sewer and irrigation systems.

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